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Swim-Training Volume and Shoulder Pain Across the Life Span of the Competitive Swimmer: A Systematic Review

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Background: Competitive swimmers are exposed to enormous volumes of swim training that may overload the soft tissue structures and contribute to shoulder pain. An understanding of training factors associated with the injury is needed before practice guidelines can be developed.

Objectives: To investigate the relationship between swim-training volume and shoulder pain and to determine swim-training volume and shoulder pain prevalence across the life span of the competitive swimmer.

Data Sources: Relevant studies within PubMed, Web of Science, and MEDLINE.

Study Selection: Studies that assessed the relationship between a defined amount of swim training and shoulder pain in competitive swimmers.

Data Extraction: Twelve studies (N = 1460 participants) met the criteria. Swimmers were grouped by age for analysis: young (<15 years), adolescent (15–17 years), adult (18–22 years), and masters (23–77 years).

Data Synthesis: Adolescent swimmers showed the highest rates of shoulder pain (91.3%) compared with other age groups (range = 19.4%–70.3%). The greatest swim-training volumes were reported in adolescent (17.27 ± 5.25 h/wk) and adult (26.8 ± 4.8 h/wk) swimmers. Differences in exposure were present between swimmers with and those without shoulder pain in both the adolescent ($P = .01$) and masters ($P = .02$) groups. In adolescent swimmers, the weekly swim-training volume ($P < .005$, $P = .01$) and years active in competitive swimming ($P < .01$) correlated significantly with supraspinatus tendon thickness, and all swimmers with tendon thickening experienced shoulder pain.

Conclusions: Evidence suggests that swim-training volume was associated with shoulder pain in adolescent competitive swimmers (level II conclusion). Year-round monitoring of the athlete's swim training is encouraged to maintain a well-balanced program. Developing athletes should be aware of and avoid a sudden and large increase in swimming volume. However, additional high-quality studies are needed to determine cutoff values in order to make data-based decisions regarding the influence of swim training.

Key Words: upper extremity, athletes, epidemiology

Swimming is a popular recreational and competitive sport among all generations. Competitive swimming careers typically begin when children enter age-group programs. However, as swimmers develop through adolescence, new challenges and the time-consuming demands of training often cause athletes to drop out.[1,2] In the United States, about 5 million swimmers were competing on high school teams, with another 336 000 active on club teams. In comparison, only 22 000 National Collegiate Athletic Association swimmers were registered in competitive leagues during 2015–2016.[3] However, because of increased participation opportunities, swimmers often reenter the sport at an older age, with about 65 000 swimmers competing at US masters levels.[3–5]

Injuries in competitive swimming primarily arise from repetitive strain and microtrauma.[6] This is not surprising when one considers the amount of swimming to which the athletes are exposed. In competitive swimming, coaches are widely known to prescribe large quantities of swim training at low intensity to enhance performance.[7–9] Because of these demanding and time-consuming training programs, competitive swimming has essentially developed into a year-round intensive sport, with athletes at young ages focusing solely on swimming.[10] During their 10- to 15-year swimming careers, swimmers often practice 5 to 7 days per week and sometimes twice daily.[11] This excessive exposure to swimming has been linked to overtraining[12,13] and increases the risk of soft tissue injury, pain, and dissatisfaction.[11,14–16] Shoulder pain is particularly frequent,[17–19] and, with prevalence rates reported as high as 91%,[15] is a major cause of missed practice.[20]

Given the high prevalence of shoulder pain across the life span of the swimmer and the high levels of swim training that come with increased competitive levels,[11,21,22] practice guidelines for reducing injury are necessary. However, to develop these guidelines, exposure or training factors that are associated with shoulder pain must first be identified.[23] Several researchers[11,14–16] have examined the association between swim-training volume and shoulder pain, but to our knowledge, the level of evidence of these studies has yet to be critically assessed among young to masters-level competitive swimmers. Therefore, the purposes of our

Table 1. Eligibility Criteria

Exclusion criteria	1. Reviews, case report and pilot studies, commentaries 2. Studies not conducted on competitive swimmers 3. Studies without reference to shoulder pain or shoulder injury as an outcome measure 4. Studies without reference to measures of training volume
Inclusion criteria	1. The article must include original data. 2. The article must be published in English. 3. The article must mention at least 1 feature defining the amount of swim training undertaken by the swimmer (hours or distance). 4. The article must provide a measure of association between training volume and shoulder pain.

systematic review were to evaluate the published evidence and to investigate the relationship between swim-training volume and shoulder pain in 4 age groups representing the swimmer's life span. In addition, this review provides an overview of reported swim-training volumes and shoulder pain prevalence across the life span of the competitive swimmer. By doing so, our goals were to increase the understanding of the relationship between swim-training volume and shoulder pain and to offer guidance in prescribing and monitoring training for professionals in the field.

METHODS

This review was conducted following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses.[24]

Information Sources and Search Strategy

To identify relevant studies, the PubMed, Web of Science, and MEDLINE databases were searched using combinations of terms covering the topics of *competitive swimmers* (*swim**) AND *training volume* (*training load* or *training volume* or *exercise* or *practice* or *training program*) AND *shoulder pain* (*shoulder pain* or *shoulder injury* or *shoulder overuse*). The search was performed by 2 researchers (A.C. and a non-author) from inception to January 2018. No limit for time of publication was used.

Eligibility Criteria

To be included in the systematic review, the studies had to report on competitive swimmers, provide a measure of swim-training volume undertaken by the participants, include shoulder pain or shoulder injury as an outcome measure, and examine the relationship between shoulder pain and training volume. All study designs except for reviews, meta-analyses, and case and pilot studies were allowed. Participants of all ages were considered eligible and included in the review.

Study Selection

A summary of the exclusion and inclusion criteria is provided in Table 1. After eliminating duplicates, 2 reviewers (A.C. and a non-author) independently assessed the articles for eligibility. All search results were independently screened based on the title and abstract. Full texts of potentially eligible studies were retrieved and again independently evaluated for inclusion. Based on consensus between the 2 reviewers and discussion with another author (S.F.), the articles were either included or excluded. Reference lists of the retrieved studies were manually searched for additional papers.

Data Extraction

Data relating to (1) characteristics of the study population (number of participants, level of competition, sex, mean age), (2) study design, (3) swim-training volume, and (4) shoulder pain (definition, prevalence or incidence) were independently extracted by 2 researchers. For comparison purposes, participants were categorized by age, based on the similarity of reported swim-training volume and competitive level: young competitive swimmers (<15 years), adolescents competing in clubs or in high school (15–17 years), adults in club competition or competitive college swimmers (18–22 years), and masters-level swimmers (23–77 years).

Swim-Training Volume. The method of monitoring and the reported data of swim-training volume were extracted as originally reported in the included studies. The method of monitoring was described as *self-reported* when individual questionnaires were used to assess swim-training volume, as *squad average* when the coach reported an average swim-training volume for the entire swimming squad, or as *follow-up* when the swim-training volume was prospectively monitored by the research team. We defined *swim-training volume* as the average distance or average time swum per week or per year. In addition, lifetime exposure to swim training was reported as the number of years swimmers participated competitively. When training data were reported per practice, swim-training volume per week was estimated by multiplying the mean distance (kilometers) of training by the average training frequency per week.

Shoulder Pain Definitions and Epidemiologic Data. We used a broad definition of musculoskeletal shoulder pain, including *time-loss injury* as "an injured or painful shoulder that leads to the athlete being unable to take full part in future training or competitive activities" and *medical-attention injury* as "an injured or painful shoulder where a qualified clinician has assessed the athlete's medical condition."[25] When shoulder pain was reported using a cutoff score on a numeric pain rating scale, the study was also included. The following injury characteristics were included[25]: all musculoskeletal (injury category) nontraumatic overuse injuries (injury mechanism) due to competition or training events and located at the shoulder (injury location).

When available, epidemiologic data were extracted from the studies. Prevalence rates were determined for each investigation by the proportion of swimmers with shoulder pain at a specific point in time. Studies monitoring new cases of shoulder pain during follow-up allowed incidence rates to be determined. For comparison purposes, incidence rates were converted to the number of cases per person-year by dividing the number of new cases of shoulder pain by

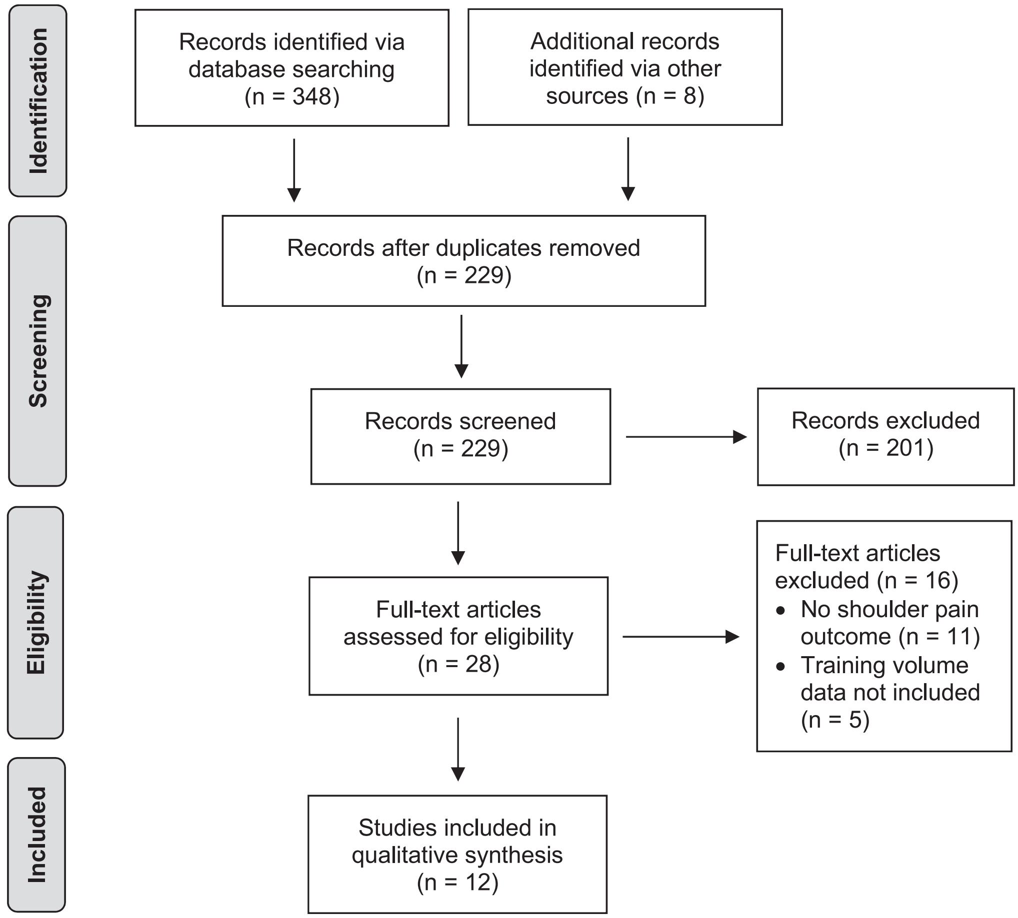

Figure. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flowchart for the study.

the sum of the time periods during which each person was observed.[26]

Risk of Bias in Individual Studies

The risk of bias of the included articles was assessed using checklists for cohort or patient control studies provided by the Dutch Institute for Healthcare Improvement. Cross-sectional studies were scored with the same checklists, but the questions that applied to cohort or case-control studies were dropped. Each question was answered using *yes*, *no*, *unclear*, or *not applicable*. The sum of all the positively scored items provided a total score for the study's risk of bias. The level of evidence of the included articles was graded using the Evidence-Based Guideline Development approach, an initiative of the Dutch Cochrane Center and the Dutch Institute for Healthcare Improvement (CBO; www.cbo.nl). Articles were given a level of evidence (A1–D) in accordance with their methodologic quality and study design. Next, a conclusion level was provided for each outcome of training volume, taking into account the level of evidence of the respective studies and the consistency of the results.[27] Conclusions were classified at 4 levels: level I conclusions were based on one A1 or on at least 2 independent A2 studies, level II conclusions were based on one A2 study or on at least 2 independent B studies, level III conclusions were based on one B or C study, and level IV conclusions were based on expert opinion only. The risk of bias was assessed independently by 2 researchers (A.C. and a non-author). Each researcher was blinded to the other's findings. Results were compared and discussed, and a final level of evidence was assigned to each study. When consensus could not be reached, the opinion of a third researcher (F.S.) was obtained.

RESULTS

Study Selection and Study Characteristics

Electronic database and manual searches returned 356 results. Screening excluded 217 articles, mainly because shoulder pain was not an outcome measure. Eight additional articles were retrieved by checking the references of relevant papers. Finally, 12 studies (N = 1460 participants) were considered eligible (Figure). Two of these investigated young competitive swimmers,[11,28] 4 included adolescents,[11,15,16,28] 7 monitored adult swimmers,[28–34] and 3 involved swimmers at the masters level.[11,35,36] Two studies[11,28] investigated competitive swimmers from the young to the masters level and stratified their participants accordingly. Detailed study characteristics are listed in Table 2.

Swim-training volume ranged between 6.64 $\pm$ 2.17 and 12.23 $\pm$ 0.15 h/wk in young,[11,28] 12.31 $\pm$ 0.21 and 17.27 $\pm$ 5.25 h/wk in adolescent,[15,28] 8.75 $\pm$ 1.36 and 26.8 $\pm$ 4.8 h/wk in adult,[31,33] and 3.78 $\pm$ 1.70 and 8.10 $\pm$ 5.10 h/wk in masters-level competitive swimmers.[11,36] Lifetime exposure to swimming increased across the life span of the swimmer and ranged from 3.28 ± 1.75 to 6.56 ± 1.45 years in young,[11] 7.65 ± 2.94 to 9.16 ± 1.80 in adolescent,[11] 9.83 ± 4.61 to 13.20 ± 4.70 in adult,[30,31] and 12.9 ± 4.5 to 22.00 ± 16.76 years in masters-level swimmers.[11,36]

The outcome measure was shoulder pain. Six of the 12 studies[11,15,28,31–33] defined shoulder pain using a numeric pain rating scale, 5 provided a time-loss or medical-attention injury definition,[16,29,30,34,36] and 1 study[35] did not supply an accurate definition. The highest rates of shoulder pain were found in adolescent swimmers (91.3%),[15] and prevalence rates of up to 20.0%,[11] 70.3%,[31] and 19.4%[11] were reported in young, adult, and masters swimmers, respectively.

Risk of Bias Within Studies

The risk-of-bias assessment and level of evidence of the articles are summarized in Table 3. In general, studies scored well for definitions of groups and follow-up. Risk-of-bias scores ranged from 3 to 6 of applicable criteria, as some criteria were not applicable in all studies. After the Evidence-Based Guideline Development method was applied, the overall body of evidence in terms of the risk of bias and design of the study was low to moderate across the age groups of competitive swimmers.

Association Between Swim-Training Volume and Shoulder Pain

The association between the volume of swim training and shoulder pain was explored in 12 studies. Authors of 4 of the 12 studies reported significant relationships in adolescent,[11,15,34] adult,[34] or masters-level[11,35] swimmers. Studies of young competitive swimmers showed no significant results.[11,28]

In a cross-sectional magnetic resonance imaging study of adolescent swimmers,[15] the number of swimming hours and weekly swimming distance correlated significantly with supraspinatus tendinopathy and shoulder impingement pain ($P < .005$ and $P = .01$, respectively). In the same study, thickness of the swimmer's supraspinatus tendon was associated with years in training ($P < .01$) and hours per week in training ($P < .05$), and all swimmers with tendon thickening presented with supraspinatus tendinopathy and shoulder impingement pain.[15] A second cross-sectional study[11] demonstrated differences in exposure of high school and masters swimmers but not young competitive swimmers ($P = .18$–.74). The number of years that high school swimmers were active in swim training was significantly associated with shoulder pain ($P = .01$). In addition, the researchers reported a greater number of hours swum per year by masters swimmers with shoulder pain compared with their pain-free counterparts ($P = .02$). A 12-month retrospective study of adolescent and adult swimmers[34] demonstrated that injured swimmers reported swimming more than noninjured swimmers (1612 versus 1380 km, $P = .04$) and that the mean number of kilometers swum was higher in swimmers with at least 1 injury versus swimmers without injury (1750 versus 1437 km, $P = .03$). A higher risk was also seen in swimmers with more than 700 exposure hours per year (odds ratio = 2.10; 95% confidence interval = 1.21, 3.61; $P = .008$). Finally, a retrospective study by Krüger et al[35] showed a negative association between exposure and pain in masters-level swimmers ($P = .004$), with a higher prevalence of shoulder pain related to lower volumes of training.

DISCUSSION

We aimed to investigate the association between swim-training volume and shoulder pain across the life span of the competitive swimmer. Grouping of the participants allowed us to investigate the relationship within similar training levels and document swim-training volume and the presence of shoulder pain throughout the life span of the competitive swimmer. Shoulder pain was most prevalent in adolescent competitive swimmers. In addition, during adolescence and early adulthood, swimmers were exposed to the greatest levels of swim-training volume. Overall, the body of evidence for an association between swim-training volume and shoulder pain was moderate (level II conclusion) in adolescent competitive swimmers and low (level III conclusion) in other age groups.

Interpretation and Exploration of the Findings

To our knowledge, this is the first synthesis of the evidence investigating the association between swim-training volume and shoulder pain across the life span of the competitive swimmer. Our finding that swim-training volume increased from the young to the adolescent and adult swimmer is in accordance with previous research[11,21] suggesting that as the competitive level increased, so did the number of training sessions and the distance per session. Young competitive swimmers performed lower volumes of swim training, making them less susceptible to overloading of the soft tissue structures about the shoulder. However, during adolescence, they were suddenly exposed to the higher volumes of swim training that come with this increase in competitive level. Investigators[37,38] suggested that these new loads or changes in loads increased the risk of injury. This evidence is consistent with our finding that adolescent developing athletes who swam more than 15 hours or 35 km per week were at a higher risk of developing tendinopathy and potentially shoulder pain.[15] In addition, studies[11,34] of developing athletes repeatedly showed an association between exposure and shoulder pain or injury incidence.

However, despite similar or even higher volumes reported in adult swimmers, results in this age group varied. This discrepancy in evidence across the life span of the swimmer can be supported with the recently introduced concept of the *acute-to-chronic load ratio*, which describes the acute (eg, last week) and chronic (eg, past 4-week average) training loads and models the relationship for injury risk.[39] In brief, this model indicates that increased injury risk may not necessarily arise because of high absolute training loads but rather from an excessive and sudden increase in acute load relative to what the athlete is prepared for.[40] Given our results, it may be that swimmers who develop through adolescence are not quite ready for the higher volumes of swim training, whereas adult swimmers have had the opportunity to adapt to these loads over time as a protective mechanism against injury. In addition, young swimmers progress through adolescence at various rates and times,[41] and although the athlete's body may not have fully matured, it is already being exposed to

Table 2. Study Characteristics[a] Continued on Next Page

Study	Design	Participant Characteristics	Age Group[b]	Method of Data Collection	Training Volume	Shoulder Pain/Injury Definition	Shoulder Pain/Injury Reporting, %: Prevalence	Shoulder Pain/Injury Reporting, %: Incidence	Evidence of Association: *P* Value(s)	Evidence of Association: Level of Evidence	Evidence of Association: Level of Conclusion
Tate et al[11] (2012)	CS (analytic)	N = 85 youth swimmers, age = 9.67 ± 1.29–13.78 ± 0.74 y	Young	SR	6.64 ± 2.17–10.94 ± 4.36 h/wk, 189.88 ± 130.58–396.00 ± 188.25 h/y, 3.28 ± 1.75–6.56 ± 1.45 y	NPRS (PSS)	20.0 (17/85)	NR	.18–.56, .54–.69, .29–.74	B	3
Tessaro et al[28] (2017)	CS (analytic)	N = 149 debutant swimmers, age = 11–15 y	Young	SR	9.15 ± 0.18–12.23 ± 0.15 h/wk,[c] 17.71 ± 5.42–27.75 ± 7.14 km/wk, 3.95 ± 1.96–6.54 ± 2.12 y	NPRS	NR	49 (73/149 over 1 y) = 0.49 cases ppy[d]	(.16), .31, .48	C	
Sein et al[15] (2010)	CS (analytic)	N = 80 club-international swimmers, age = 15.9 ± 2.7 y (53% male)	(Young), adolescents	SR	16 (8–29) h/wk = 17.27 ± 5.25 h/wk,[c] 40 (9–110) km/wk = 49.87 ± 25.25 km/wk, 8 (2–17) y = 8.88 ± 4.22 y[c]	NPRS (SSQ)	91.3 (73/80)	NR	<.005[e,g] to <.05[f] (+), .01[f,g] (+), <.01[e] (+)	B	2
Walker et al[16] (2012)	Cohort (prosp)	N = 74 state-international swimmers, age = 15 ± 3 y (50% male)	(Young), adolescents	SA	44 ± 15 km/wk	TL (SIP; SSI = SIP ≥ 2 wk)	NR	60.8 (45/74 over 1 y) = 0.61 cases ppy[d]	.07–.1	B	
Tate et al[11] (2012)	CS (analytic)	N = 84 high school swimmers, age = 16.31 ± 1.30–16.79 ± 1.27 y	Adolescents	SR	15.94 ± 6.19–16.53 ± 5.54 h/wk, 600.30 ± 392.11–652.02 ± 302.07 h/y, 7.65 ± 2.94–9.16 ± 1.80 y	NPRS (PSS)	22.6 (19/84)	NR	.71, .60, .01[f,g] (+)	B	
Tessaro et al[28] (2017)	CS (analytic)	N = 33 moderate level swimmers, age = 15–18 y	Adolescents	SR	12.31 ± 0.21 h/wk,[c] 31.23 ± 8.23 km/wk, 8.70 ± 2.49 y	NPRS	NR	66.6 (22/33 over 1 y) = 0.67 cases ppy[d]	(.16), .31, .48	C	
Ristolainen et al[34] (2014)	CC (retrosp)	N = 154 national swimmers, age = 18.6 ± 2.9 y	(Adolescents), adults	SR	767 ± 326 h/y, 1380–1612 km/y, 9.9 ± 3.1 y	MA/TL	NR	39.6 (61/154 over 1 y) = 0.40 cases ppy[d]	.008[e,f] (+), .03[f,g] (+)	B	3
Tessaro et al[28] (2017)	CS (analytic)	N = 15 advanced swimmers, age = 18–20 y	Adults	SR	13.17 ± 0.10 h/wk,[c] 34.36 ± 6.86 km/wk, 11.00 ± 2.03 y	NPRS	NR	40 (6/15 over 1 y) = 0.40 cases ppy[d]	(.16), .32, .48	C	
de Almeida et al[30] (2015)	CS (descr)	N = 257 national swimmers, age = 20.1 ± 3.8 y (54.4% male)	Adults	SR	57.1 ± 29.9 km/wk, 13.2 ± 4.7 y	MA/TL	9.3 (24/257)	26.1 (67/257 over 1 y) = 0.26 cases ppy[d]	.61, .17	C	
Chase et al[29] (2013)	Cohort (prosp)	N = 34 collegiate swimmers, age = 19.47 ± 1.4 y (53% male)	Adults	FU	25.6 km/wk,[c] 11.0 ± 3.44 y	MA/TL	NR	35.3 (12/34 over 8 mo) = 0.18 cases ppy[d]	NR	B	

Table 2. Continued from Previous Page

Study	Design	Participant Characteristics	Age Group[b]	Method of Data Collection	Training Volume	Shoulder Pain/Injury Definition	Shoulder Pain/Injury Reporting, %: Prevalence	Shoulder Pain/Injury Reporting, %: Incidence	Evidence of Association: P Value(s)	Evidence of Association: Level of Evidence	Evidence of Association: Level of Conclusion
Harrington et al[31] (2014)	CS (analytic)	N = 37 collegiate swimmers, age = 19.5 ± 1.19 y (100% female)	Adults	SR	8.75 ± 1.36–18.78 ± 2.43 h/wk, 9.83 ± 4.61–11.50 ± 3.81 y	NPRS (DASH > 6/20, PSS ≥ 4/10)	70.3 (26/37)	NR	.77–.97, .08–.59	B	
Hidalgo-Lozano et al[32] (2012)	CS (analytic)	N = 34 international swimmers, age = 21 ± 3.0 y (53% male)	Adults	SR	24.3 ± 3.5–24.8 ± 3.8 h/wk	NPRS (≥4/10, ≥3 mo)	NR	NR	.73	B	
Hidalgo-Lozano et al[33] (2013)	CS (analytic)	N = 35 International swimmers, age = 20 ± 3 y (51% male)	Adults	SR	26.1 ± 5.5–26.8 ± 4.8 h/wk	NPRS (≥ 4/10, ≥ 3 mo)	NR	NR	.13	B	
Su et al[36] (2004)	CC	N = 40 local club and collegiate swimmers, age = 23.6 ± 4.6–24.2 ± 6.5 y (48% male)	(Adults), masters	SR	7.6 ± 5.3–8.1 ± 5.1 h/wk, 12.9 ± 4.5–14.2 ± 5.0 y	TL and phase II–III Neer and Welch's shoulder grading[f]	NR	NR	.80, .39	B	3
Tate et al[11] (2012)	CS (analytic)	N = 67 masters swimmers, age = 41.72 ± 13.97–43.77 ± 12.77 y	Masters	SR	3.78 ± 1.70–4.77 ± 1.54 h/wk, 163.88 ± 81.22–223.60 ± 81.81 h/y, 15.36 ± 13.21–22.00 ± 16.76 y	NPRS (PSS)	19.4 (13/67)	NR	.06, .02,[g] .13	B	
Krüger et al[35] (2012)	CS (descr)	N = 282 national masters, age = 25–94 y (48.9% male)	Masters	SR	10–4999 m/wk (low), 5000–11 999 m/wk (medium), >12 000 m/wk (high)	NR	NR	62.4 (176/282 over 3 y) = 0.21 cases ppy[d]	.004 (–)[e]	C	

Abbreviations: CC, case-control; CS, cross-sectional; DASH, Disability of the Arm, Shoulder and Hand questionnaire; descr, descriptive; FU, follow-up; MA, medical attention; NPRS, numeric pain rating scale; NR, not reported; ppy, per person-year; prosp, prospective; PSS, Penn Shoulder Score; retrosp, retrospective; SA, squad average; SIP, significant interfering pain; SR, self-reported; SSI, significant shoulder injury; SSQ, Shoulder Service Questionnaire; TL, time loss due to training cessation.

[a] Data are expressed as mean ± SD or median (range).
[b] Age groups: young, <15 years; adolescents, 15–17 years; adults, 18–22 years; masters, 23–77 years.
[c] Manually calculated by multiplying frequency with training duration/distance or estimated mean values based on median and range.[52]
[d] Converted incidence rates to number of cases per person-year.[26]
[e] $P < .01$.
[f] Neer CS 2nd. Anterior acromioplasty for the chronic impingement syndrome in the shoulder. *J Bone Joint Surg Am*. 1972;54(1):41–50.
[g] $P < .05$

Table 3. Scores on the Risk-of-Bias Assessment of the Cohort and Patient Control Studies[a]

Study	1	2	3	4	5	6	7	Total	Level of Evidence
Cross-sectional									
de Almeida et al[30] (2015)	NA	+	+	NA	NA	NA	NA	2/2	C
Harrington et al[31] (2014)	+	+	+	NA	NA	NA	?	3/4	B
Sein et al[15] (2010)	+	+	+		NA	NA	–	3/4	B
Tate et al[11] (2012)	+	+	+	NA	NA	NA	–	3/4	B
Tessaro et al[28] (2017)	+	+	+	NA	NA	NA	–	3/4	C
Hidalgo-Lozano et al[32] (2012)	+	+	+	NA	+	+	+	6/6	B
Hidalgo-Lozano et al[33] (2013)	+	+	+	NA	+	+	+	6/6	B
Krüger et al[35] (2012)	–	+	+	NA	?	–	–	2/6	C
Case-control									
Ristolainen et al[34] (2014)	+	+	+	NA	?	+	+	5/6	B
Su et al[36] (2004)	+	+	+	NA	+	–	+	5/6	B
Cohort									
Chase et al[29] (2013)	+	–	+	+	NA	NA	+	4/5	B
Walker et al[16] (2012)	+	–	+	–	NA	NA	+	3/5	B

Abbreviations: +, positive score; –, negative score; ?, unclear; NA, not applicable.

[a] Questions: (1) Are the comparison groups adequately defined? (2) Was participant selection sufficiently valid? (3) Were outcome and exposure assessed independently (blinded)? (4) In cohort: Is there a sufficient follow-up period? (5) In case-control: Were new cases (incidents) selected? (6) In case-control: Can misclassification be sufficiently excluded? (7) Were the most important confounders or prognostic factors taken into account in the analysis?

enormous volumes of swim training. Combined with the extreme stresses due to repetitive motion, the periods of rapid growth during adolescence can predispose the athlete to injury and shoulder pain,[42] supporting our findings.

Our results may also be partially explained by studies that explored the effects of cross-training. Participation in other sports has been proposed to improve overall fitness, trunk muscle endurance, and strength and thereby possibly aid in preventing injury.[43] Tate et al[11] found that both young and masters-level swimmers also participated in sports such as soccer, running, and walking, which allowed relative rest for the shoulders. However, adolescents were more active in water polo, which entails repetitive movements of the shoulder. This may further support our finding that shoulder pain was more prevalent in adolescent competitive swimmers than in other age groups.[11]

The discrepancy in evidence may not necessarily arise from significant differences in training volume but perhaps from variations in managing one's own training program. Although adolescent competitive swimmers may be more exposed to training demands when under the supervision of an adult coach, the larger variability in reported training volume of adult swimmers may point to adults self-regulating and limiting their own training to prevent injury. In addition, developing athletes continuously face greater pressure to remain competitive and often push training to its limits to maximize performance.[44] This increased pressure to perform may also influence the athlete's behavior toward injury; 85% of adolescent competitive swimmers believed that mild shoulder pain was normal and that they should tolerate it to be successful.[45] Many of these adolescent swimmers believed they should continue training despite pain, but pain contributes to alterations in motor control and neuromuscular adaptations, increasing the risk of further injury.[46] This again supports the results of our review that consistently greater training volumes were reported in both adolescent and adult swimmers, yet adolescent swimmers experienced higher rates of shoulder pain.

Finally, athletes' individual and sport-specific differences may confound the relationship between swim-training volume and shoulder pain. The athlete's total workload and physical and psychosocial status can influence the central nervous system, which contributes to the ability to tolerate high training loads and cope with fatigue.[47,48] Adolescent athletes typically encounter time conflicts and start to pursue interests outside of competitive swimming,[1] which may increase their total workload and support the higher prevalence of pain and injury reported in this group.

Practical Implications and Recommendations for Professionals Working With Swimmers

We propose an evidence-based platform that improves our understanding of the relationship between swim-training volume and shoulder pain across the life span of the competitive swimmer. Although the limited available data on competitive swimmers make it difficult to provide sport-specific practice guidelines, our review highlights a number of general points that may serve as practical recommendations in the future.

First, based on the available evidence, prescribing large quantities of swim training during the transition from young to adolescent ages may increase the risk of injury[37,38] and lead to early specialization in the sport. For athletes focusing solely on swimming, the risks of injury, overtraining, and dropout may increase.[49] Swimming coaches should be aware of and limit sudden alterations in swim-training volume that may come with an increase in the competitive level or a change in the training stage. The athlete's acute and chronic swim-training volume should be monitored year-round and compared with the data provided in this review. A well-balanced and gradually increasing training program may allow the athlete to be better prepared and protected for upcoming periods of intensified training.

Second, our results also highlight the importance of participating in other sports. Although we cannot conclude that cross-training offers a protective effect against injury, coaches should be aware of and encouraging about the athlete's participation in other activities to prevent early specialization.[10] In addition, sport programs for the young should focus on the developing individual rather than simply on the performing athlete.[1]

We also draw special attention to the relevance of education and advice on injury and its contributing factors. In particular, the findings of this study underline the importance of tackling the beliefs and attitudes of adolescent competitive swimmers, who should be aware of the risk of further injury when they continue to train despite pain.[46] Educating developing athletes about stress and load management may also help to minimize the effects of external load and reduce the likelihood of injury.[44] Sports governing bodies should be alert to the increasing pressure that developing athletes face and beliefs about and attitudes toward injury that may accompany this pressure. The health of the athletes must be paramount when planning event calendars and overall competition loads.

Finally, athletes may differ greatly in their response and adaptation to training.[44] As sport-specific and individual differences may also contribute to the development of shoulder pain in swimmers, our findings emphasize the importance of prescribing swim-training volume on an individual and flexible basis, with special attention to those who are at increased risk of injury.

Study Limitations and Recommendations for Monitoring Training Load in the Future

Our results should be considered in light of the acknowledged limitations of both the included studies and this review. First, the attempt to explore associations between training volume and shoulder pain was limited by disparities in the reporting of the former and the lack of a universal definition of the latter. The authors of all but 2 of the included studies reported swim-training volume per week. However, because of the variability of reporting in hours and distance, a standardized variable of swim-training volume could not be determined. Moreover, information on swim-training volume was often obtained using self-reported registration forms (6 of 12 studies), which may have increased the response bias, depending on when the study was performed during the season. It can also be argued that the definition of swimmer's shoulder pain influenced the results of epidemiologic research.[50] Clearly, consistency in the reporting of swim-training volume and a universal definition of shoulder pain are recommended in future research.

Also, growing evidence indicates that the athlete's total training load cannot be represented by a single measure of external load (eg, training volume) but must also consider relative contributions of internal load[44,51] such as the swimmer's history and physiological and psychosocial factors, as well as training intensity and the amount of dry-land training. Future researchers aiming to monitor the swimmer's training load should start with reliable and simple measures that are relevant to the sport and its key injuries. Over time, more complex measures can be combined to accurately measure the athlete's total work-load, representing both external and internal factors. Finally, coaches and athletes should be more involved in studies, understand what they are trying to achieve, and encourage compliance.

Despite the guiding results of this review, the lack of high-quality studies in the literature did not allow us to draw strong, data-based conclusions regarding the influence of swim training on shoulder pain. In addition, cutoff values of pain-free swim training are necessary and should be based on normative data. This may further help clinicians identify swimmers at risk and prevent injury in the future. Finally, we investigated the association between swim-training volume and shoulder pain and, therefore, a cause-and-effect relationship cannot be assumed.

CONCLUSIONS

In this systematic review, we provided information about the association between swim-training volume and shoulder pain in competitive swimmers. As a group, adolescent competitive swimmers showed the highest prevalence of shoulder pain and a moderate level of evidence for a relationship with swim-training volume. Year-round monitoring of both acute and chronic swim-training volume is recommended to maintain a well-balanced and progressively increasing training program. In addition, we advise against large increases in swim-training volume between successive training levels, especially in competitive adolescent swimmers. In the future, high-quality studies are needed to determine cutoff values for pain-free swim-training volumes across the life span of the swimmer. However, until more evidence is available to enable strong data-based decisions, professionals working with these athletes should be aware of the increased likelihood of shoulder pain when prescribing greater volumes of swim training during adolescence.

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